The NOAA Climate Reanalysis Task Force Technical Workshop

Gilbert P. Compo

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Task Force mission:

Address outstanding issues in atmospheric, oceanic, and land reanalysis

Develop a greater degree of integration among Earth system reanalysis components.

Integrate with national and international efforts.

Leads: Arun Kumar, Gilbert Compo; co Leads: James Carton, Suru Saha

Organized by CPO– Modeling, Analysis, Predictions, and Projections

http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/ClimateReanalysisTaskForce.aspx

Reanalyses.org [Advancing Reanalysis], monthly telecons (need to login)

Participant	Affiliation
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Suranjana Saha (Co-Lead)	NOAA Environmental Modeling Center (EMC)
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Rongqian Yang	NOAA Environmental Modeling Center (EMC)
Lisan Yu	Woods Hole Oceanographic Institution
Mike Bosilovich	NASA Goddard
Dick Dee	European Centre for Medium-Range Weather Forecasts

http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/ClimateReanalysisTaskForce/Participants.aspx

Projects

Research towards the next generation of NOAA Climate Reanalyses
PI: Arun Kumar

Improving the Land Surface Components of the CFS Reanalysis
PI: Michael Ek

Exploration of advanced ocean data assimilation schemes at NCEP
PI: James Carton

Improving the Prognostic Ozone Parameterization in the NCEP GFS and CFS for Climate Reanalysis and Operational Forecasts
PI: Gilbert Compo

Strategies to Improve Stratospheric Processes in Climate Reanalysis
PI: Craig Long

Evaluating CFSR Air-Sea Heat, Freshwater, and Momentum Fluxes in the context of the Global Energy and Freshwater Budgets
PI: Lisan Yu

Diagnosing and quantifying uncertainties of the reanalyzed clouds, precipitation and radiation budgets over the Arctic and Southern Great Plains using combined surface-satellite observations
PI: Xiquan Dong

Projects

Research towards the next generation of NOAA Climate Reanalyses
PI: Arun Kumar [Next Presentation]

Improving the Land Surface Components of the CFS Reanalysis
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Improve Reanalysis Components in Atmosphere, Land, and Ocean

Exploration of advanced ocean data assimilation schemes at NCEP
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Improve Stratosphere

Strategies to Improve Stratospheric Processes in Climate Reanalysis
PI: Craig Long

Evaluating CFSR Air-Sea Heat, Freshwater, and Momentum Fluxes in the context of the Global Energy and Freshwater Budgets
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Diagnoses to evaluate and speed Improvements

Diagnosing and quantifying uncertainties of the reanalyzed clouds, precipitation and radiation budgets over the Arctic and Southern Great Plains using combined surface-satellite observations
PI: Xiquan Dong

NOAA Climate Reanalysis Task Force Technical Workshop

Organizers: Jim Carton, Gilbert Compo, Arun Kumar, Suru Saha, Heather Archambault

Workshop Objectives

- Report on NOAA Climate Reanalysis Task Force progress
- Exchange reanalysis approaches, algorithms, and techniques currently in use and under development.
- Discuss techniques for addressing outstanding issues in the reanalysis efforts, e.g., presence of spurious discontinuities and trends, coupling of Earth System components, inclusion of new areas such as aerosols.
- Identify the various requirements for reanalysis products.
- Determine strategies and overlaps for national and international reanalysis efforts based on scientific drivers for climate and weather research.

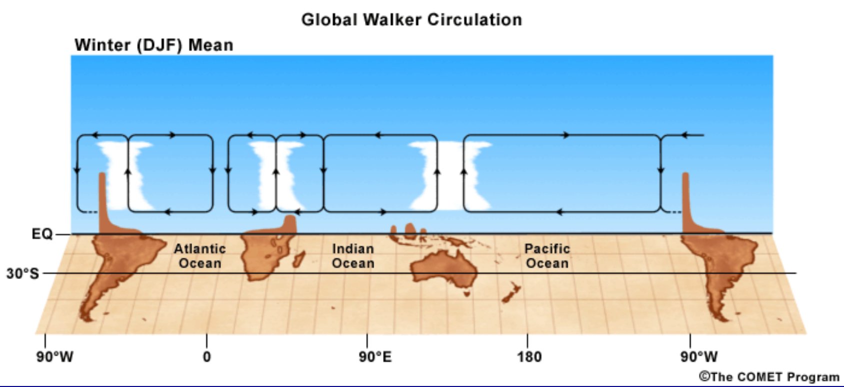
Is the Pacific Walker Circulation changing in response to Global Warming?

Results from
Sandeep, Stordal, Sardeshmukh, and Compo 2014 (Cli. Dyn., http://dx.doi.org/10.1007/s00382-014-2135-3)

Yes, PWC seems to be strengthening in several observational datasets.

Yes, PWC seems to be weakening in coupled model simulations.

Walker Circulation is the east-west part of the global overturning circulation.



As global temperature increases,
global water vapor increases faster than precipitation in coupled climate models forced with greenhouse gases.

Overturning circulation (global convective mass flux) must **weaken** to compensate [*Held and Soden 2006*].

- Sea Level Pressure-based Pacific Walker Circulation used as proxy to investigate:

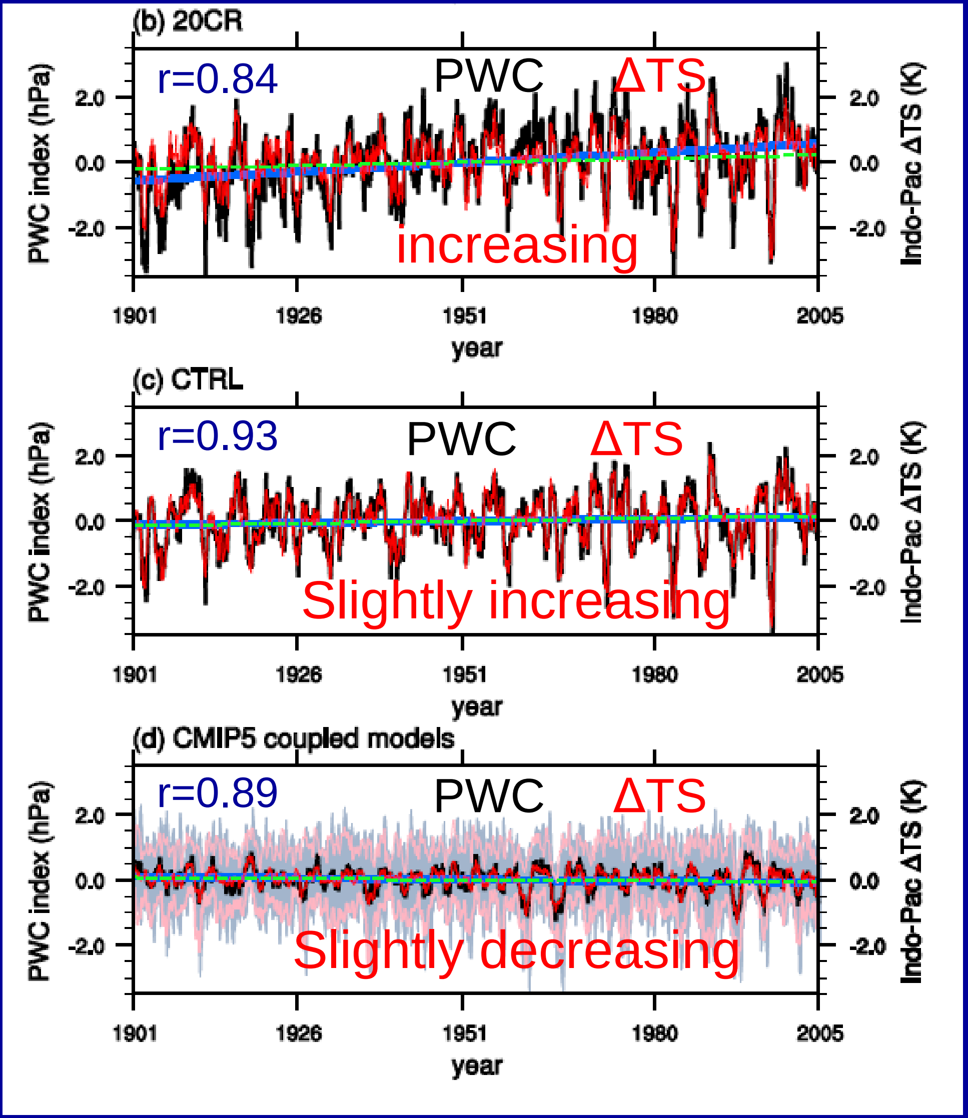
Vecchi et al. 2006 and others found weakening.
Meng et al. 2012 and others found strengthening.
Solomon and Newman 2012 found no change.

Anomalies of SLP-based Pacific Walker Circulation PWC and West minus East Equatorial Pacific SST gradient ΔTS

20CR (only pressure assimilated)

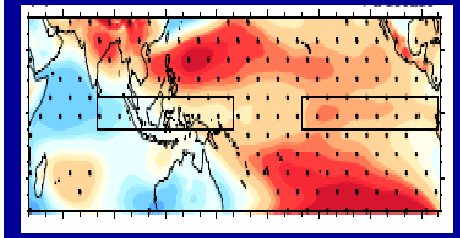
SST-forced CAM4 (3 members)

Radiative forcings CMIP5 (12 models)



ΔTS from HadISST1

ΔTS is average of HadISST1, ERSSTv3b, COBE1

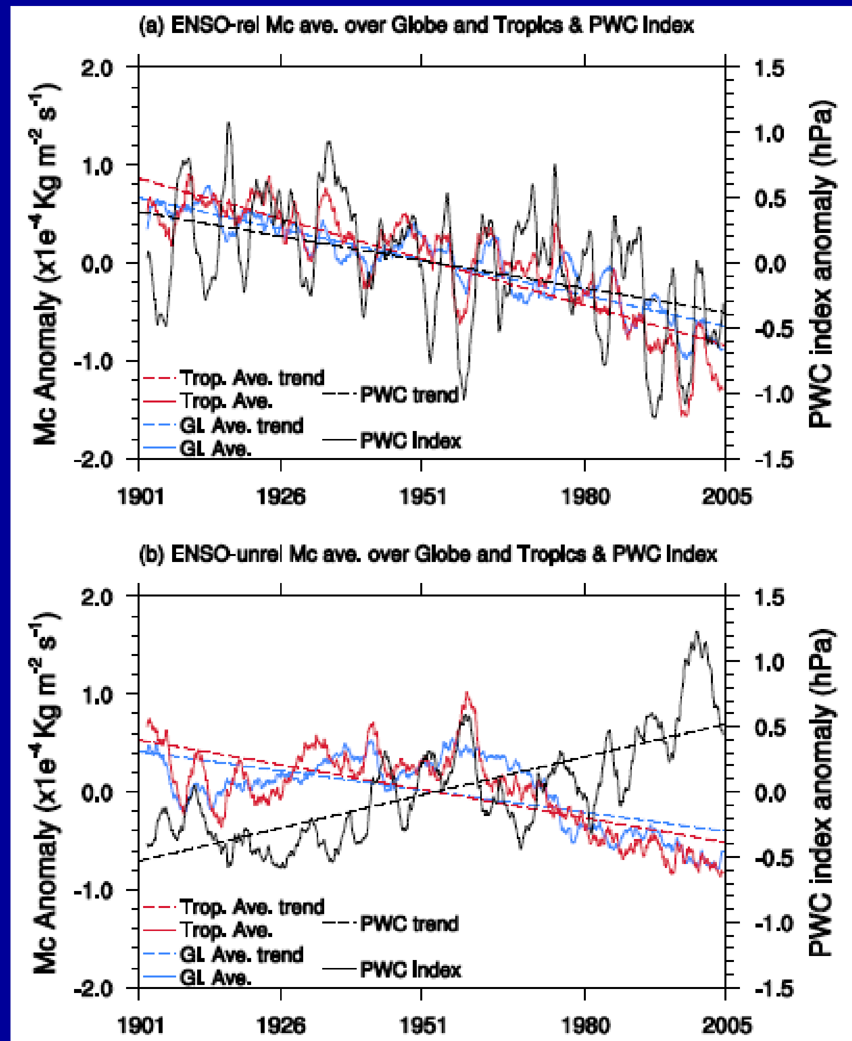


Sandeep et al. 2014

PWC trends and variability are closely related to ΔTS

PWC compared to convective mass flux (Mc) in ENSO-related and ENSO-unrelated SST-forced CAM4 simulations

SSTs filtered to retain ENSO
(3 members)



(Pacific SST gradient ΔTS weakens)

PWC
Tropical Mc
Global Mc

SSTs filtered to remove ENSO
(3 members)

(Pacific SST gradient ΔTS strengthens)

Sandeep et al. 2014

Global convective mass flux **<u>decreases</u>** as globe warms regardless of whether Pacific Walker Circulation weakens or strengthens.

Conclusions

1. NOAA Climate Reanalysis Task Force is researching reanalysis improvements and outstanding issues. Example: Pacific Walker circulation.

2. Pacific Walker Circulation trends and variability depend on definition. SLP-based definition closely related to SST gradient; almost unrelated even to *Tropical* overturning circulation.

3. SLP-based PWC index is ***not a proxy*** for global or tropical convective mass flux. Global arguments cannot be applied to regional circulation.

4. PWC appears to be strengthening over past century in reanalyses and SST-forced AGCM simulations.

5. SST-forced AGCM and GHG-forced CMIP5 historical simulations agree that global and tropical convective mass flux is weakening.

6. Some Goals of Reanalysis: improve representation and reduce uncertainty of climate trends, such as global overturning circulation.

Responsibility of Speakers: Stick to time, 80% for presentation, 20% for questions

Responsibility of All Attendees: Interact, Discuss, Ask questions, *Discuss more*.

Can use reanalyses.org/workshop2015 to leave comments, thoughts, and questions.

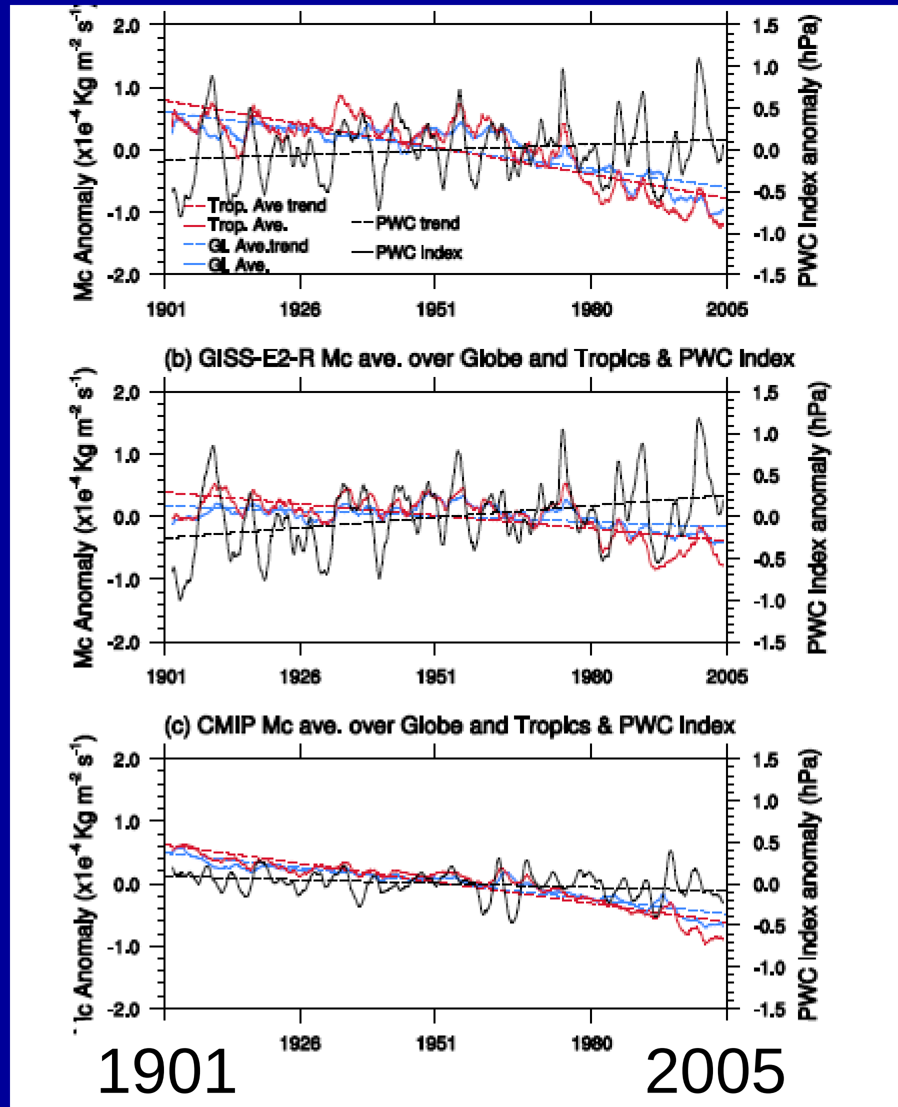
Extra Slides

Pacific Walker Circulation compared to Convective Mass Flux (Mc) from SST-forced and coupled GCMs

SST-forced CAM4 (3 members)

SST-forced GISS-E2-R (4 members)

Radiatively forced CMIP5 (12 models)



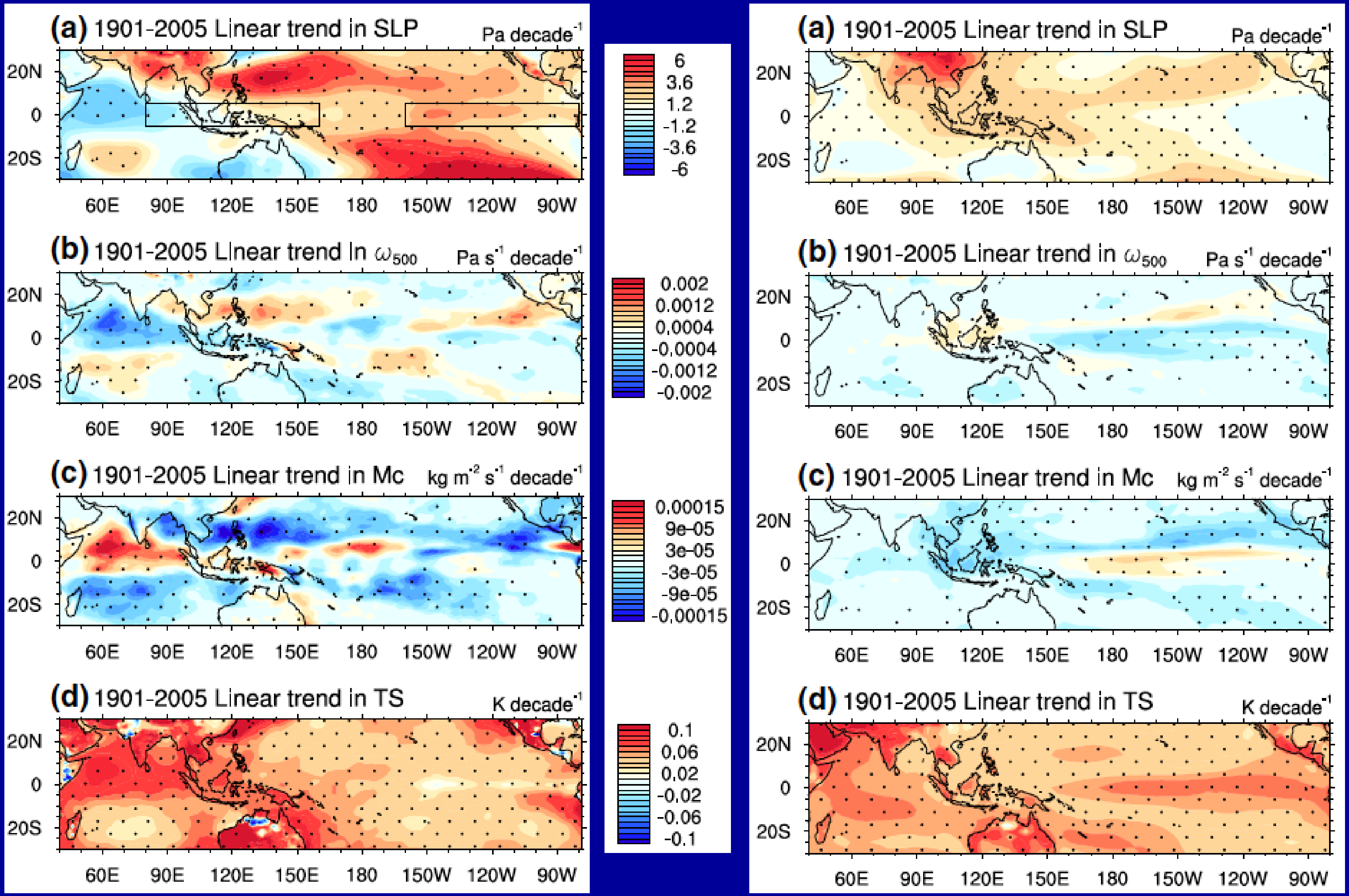
PWC
Tropical Mc
Global Mc

Sandeep et al. 2014

Correlation between Pacific Walker Circulation and convective mass flux is low for all simulations. Trends can be opposite.

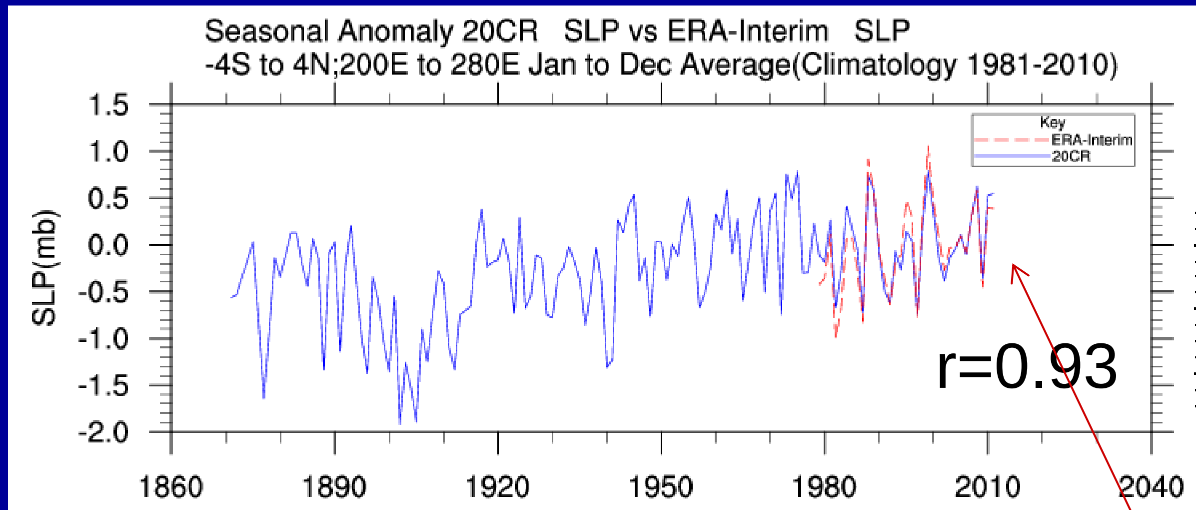
SST and radiatively forced trends (1901-2005)

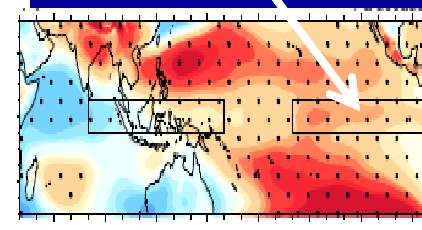
SST-forced CAM4 (3 members) CMIP5 (12 models)

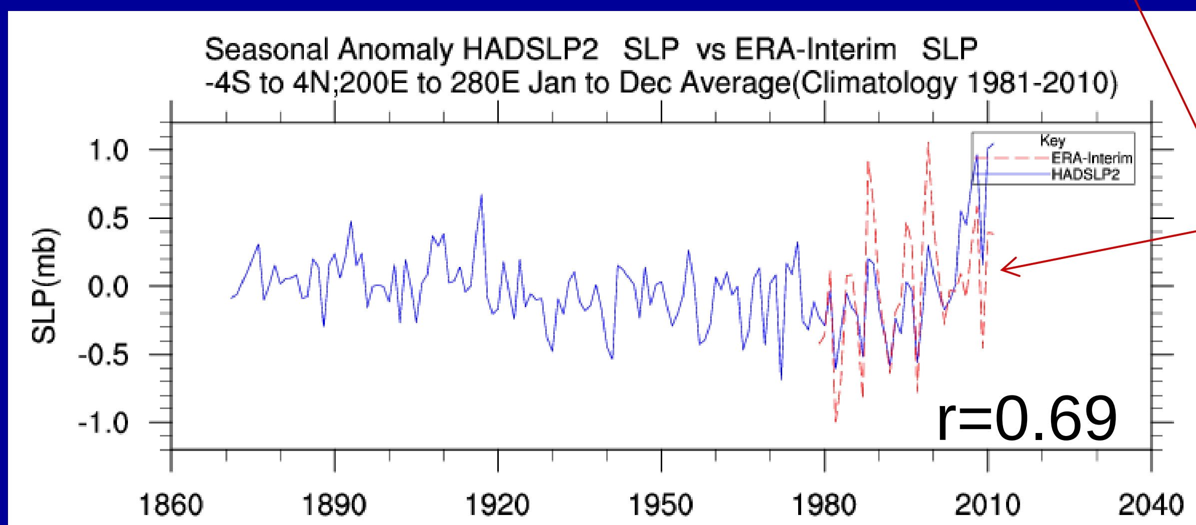


Different trends in various facets of Walker Circulation

Annual anomalies of Eastern box of SLP-based PWC





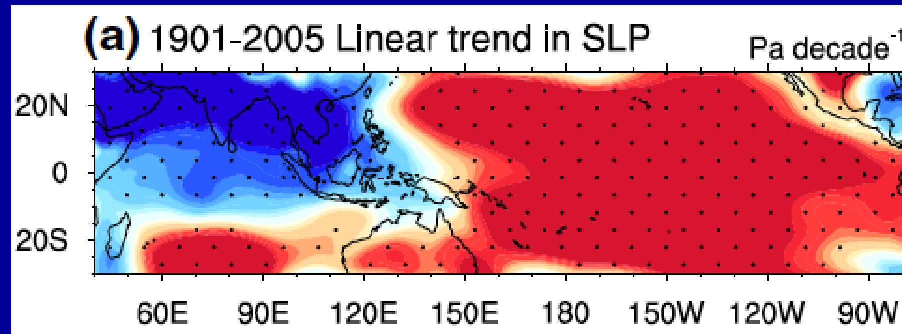


NOTE: Change of Scale! ERA-Int is the same curve

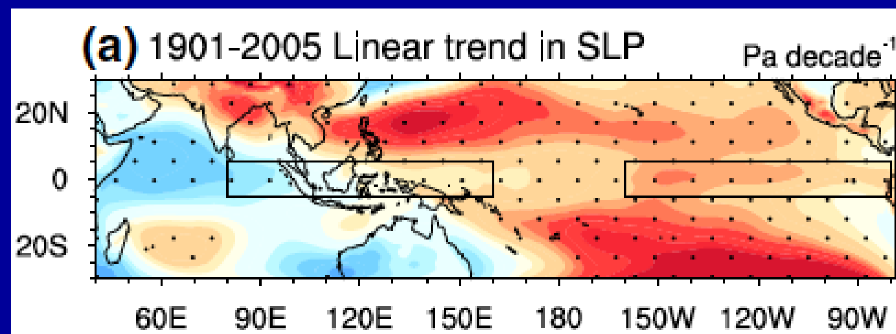
HadSLP2r has spurious increase after 2005 (becomes adjusted NCEP-NCAR reanalysis). Variance is consistently less than ERA-Int or 20CR. HadSLP2r correlation is lower with ERA-Int compared to 20CR.

Reanalysis, SST and radiatively forced trends (1901-2005)

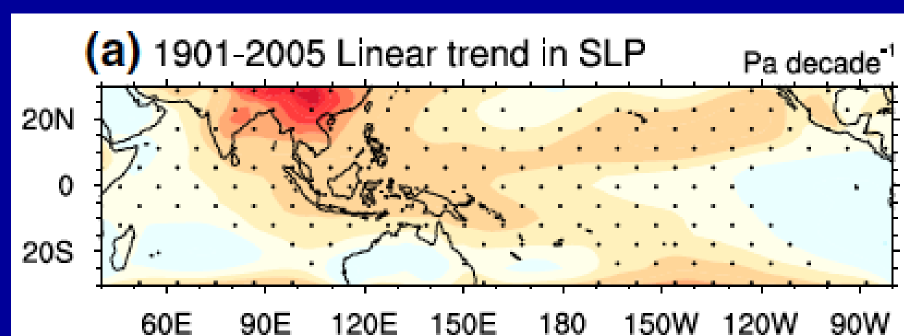
20th Century Reanalysis 20CR

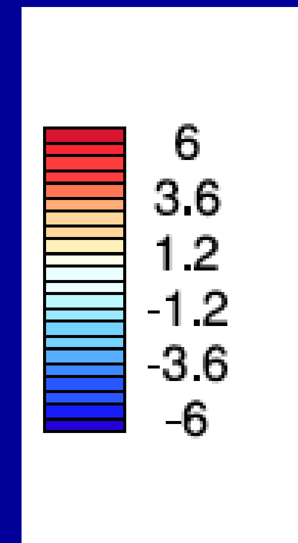


SST-forced CAM4 (3 members)



Radiatively forced CMIP5 (12 models)



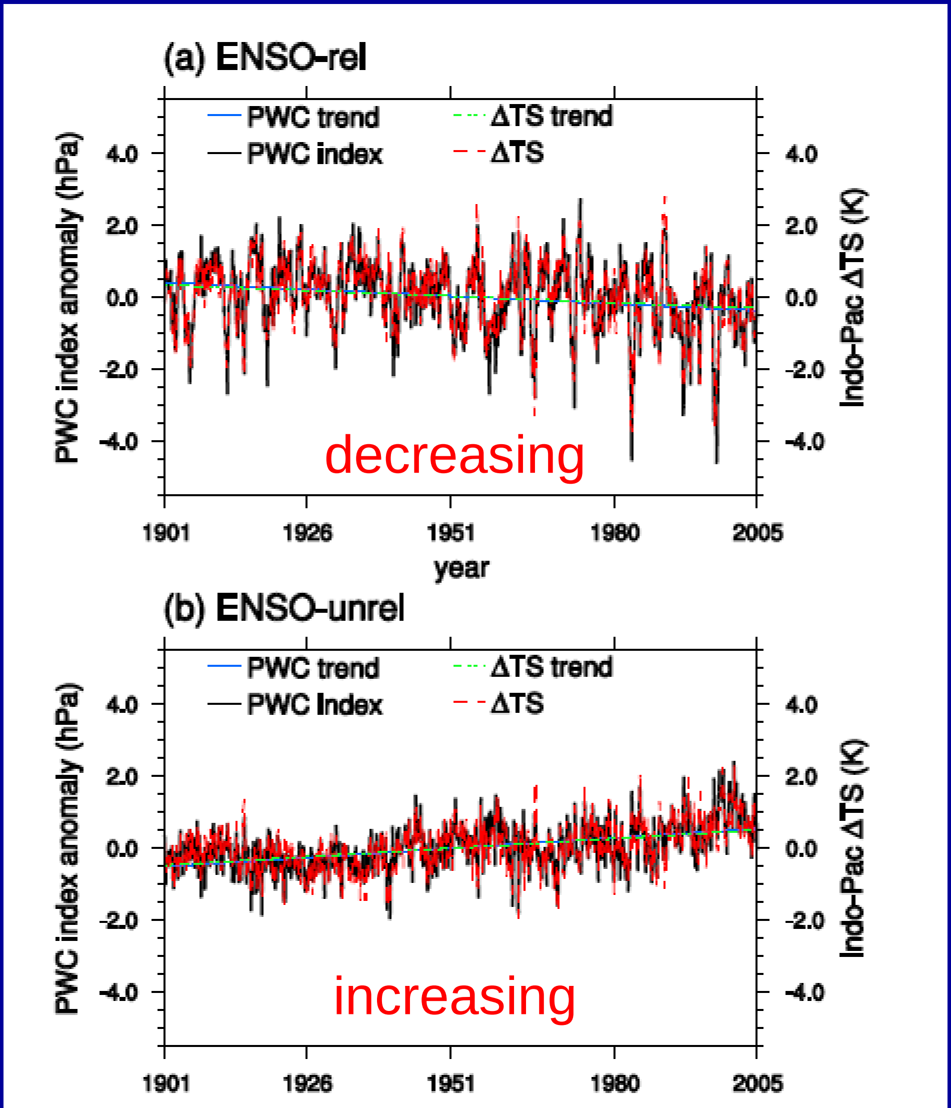


20CR trends agree better with SST-forced ensemble.
What is 20CR trend sensitivity to SST boundary condition?

CAM4 AGCM simulations forced by ENSO-related and ENSO-unrelated SSTs (filter from *Compo and Sardeshmukh 2010*)

SSTs filtered to retain ENSO (3 members)

SSTs filtered to remove ENSO (3 members)

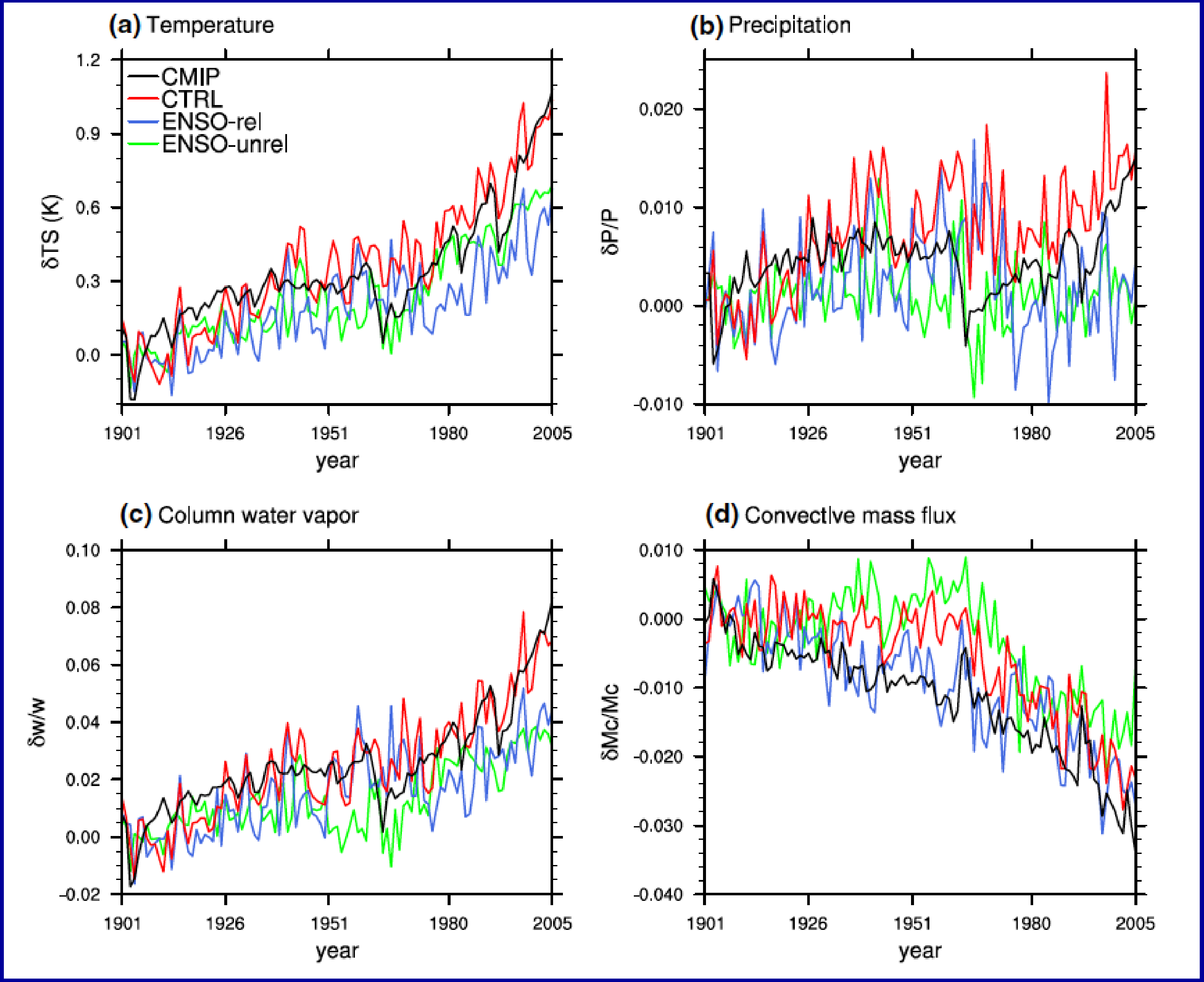


ΔTS is average of HadISST, ERSSTv3b, COBE

Sandeep et al. 2014

Opposite SST gradient trends (ΔTS) force opposite PWC trends.

Change relative to 1901 to 1910 mean



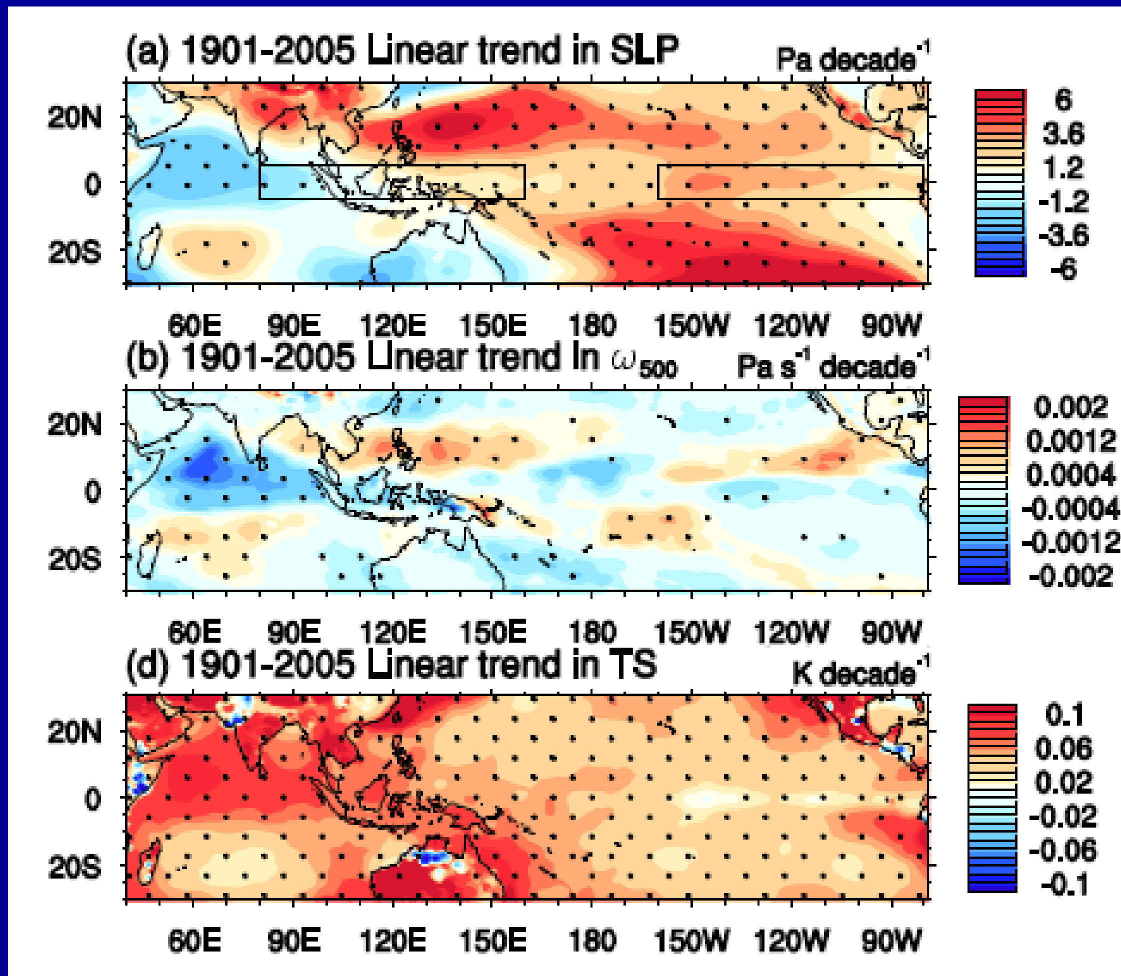
Sandeep et al. 2014

1901-2005 Linear Trend from CAM4 SST-forced simulations (3 ensemble members)

Sea Level Pressure

500 hPa vertical velocity

Land and Sea Surface Temperature



Each ensemble member has different SST dataset prescribed.

Average of HadISST1, ERSSTv3b, COBE SST

Sandeep et al. 2014

Trend patterns of SLP and vertical velocity correlate moderately (r=0.41).

Stratospheric Ozone

- A key radiatively active constituent in both solar and infrared radiation
- Affects temperature of stratosphere, troposphere, and surface
- Reduces harmful ultraviolet light reaching surface
- Ozone variations play role in climate variability of Northern and Southern Hemisphere
- Reanalysis systems, and the weather models on which they rely, must accurately represent the ozone field and its effect on climate variations.
- Complete ozone photochemistry is too computationally intensive to include in current weather and climate models
- So, parameterize processes!

Ensemble Filter Algorithm (Whitaker and Hamill, 2002)

Ensemble mean

$$\bar{\mathrm{x}}_j^{\mathrm{a}} = \bar{\mathrm{x}}_j^{\mathrm{b}} + \mathrm{K}\left(y^{\mathrm{o}} - \bar{y}_j^{\mathrm{b}}\right),$$

Ensemble deviations

$$\mathrm{x}_j'^{\mathrm{a}} = \mathrm{x}_j'^{\mathrm{b}} - \tilde{\mathrm{K}}\left(y_j'^{\mathrm{b}}\right),$$

Sample Kalman Gain

$$\mathrm{K} = \mathrm{P^b H^T}(\mathrm{H P^b H^T} + R)^{-1}$$
$$= \frac{1}{n-1}\sum_{j=1}^{n} \mathrm{x}_j'^{\mathrm{b}} y_j'^{\mathrm{b}} \left(\frac{1}{n-1}\sum_{j=1}^{n} y_j'^{\mathrm{b}} y_j'^{\mathrm{b}} + R\right)^{-1}$$

Sample Modified Kalman Gain

$$\tilde{\mathrm{K}} = \left(1 + \sqrt{\frac{R}{\mathrm{H P^b H^T} + R}}\right)^{-1} \mathrm{K},$$

$\mathbf{x}_j = \bar{\mathbf{x}} + \mathbf{x}'_j$ is pressure, air temperature, winds, humidity, etc. at all levels and gridpoints, every six hours.

y^o is only observations of hourly and synoptic **surface pressure**,

$\mathbf{y}^b = \mathbf{H}\mathbf{x}^b$ is guess surface pressure

20th Century Reanalysis implementation of Ensemble Filter Algorithm

(Whitaker et al. 2004, Compo et al. 2006, Compo et al. 2011)

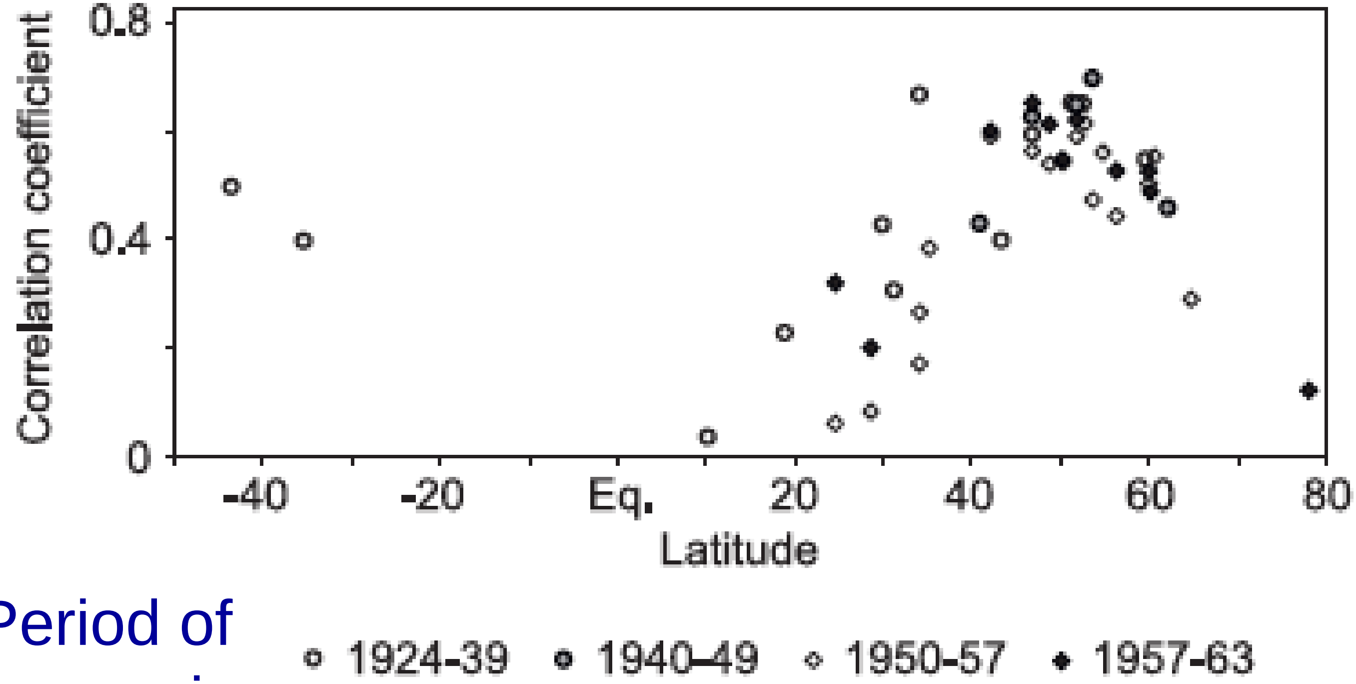
Algorithm uses an ensemble of GCM runs to produce the weight **K** that varies with the atmospheric flow and the observation network every 6 hours

Using 56 member ensemble, HadISST1.1 prescribed SST and sea ice monthly boundary conditions (*Rayner et al. 2003*)
1871-2011: T62, 28 level NCEP GFS08ex atmosphere/land model
9 hour forecasts for 6 hour centered analysis window
- time-varying CO_2, solar and volcanic radiative forcing
- prognostic stratospheric ozone

Sampling and Model error parameterizations:
-Covariance localization (4000 km, 4 scale heights) and
-Latitude and time dependent multiplicative covariance inflation (alpha = 1.01 to 1.12) [*Anderson and Anderson, 1999*; *Houtekamer and Mitchell, 2001; Hamill et al. 2001; Whitaker et al., 2004*]

http://go.usa.gov/XTd Compo et al. 2011, doi:10.1002/qj.776

Column ozone from stations compared to 20CR



Period of comparison

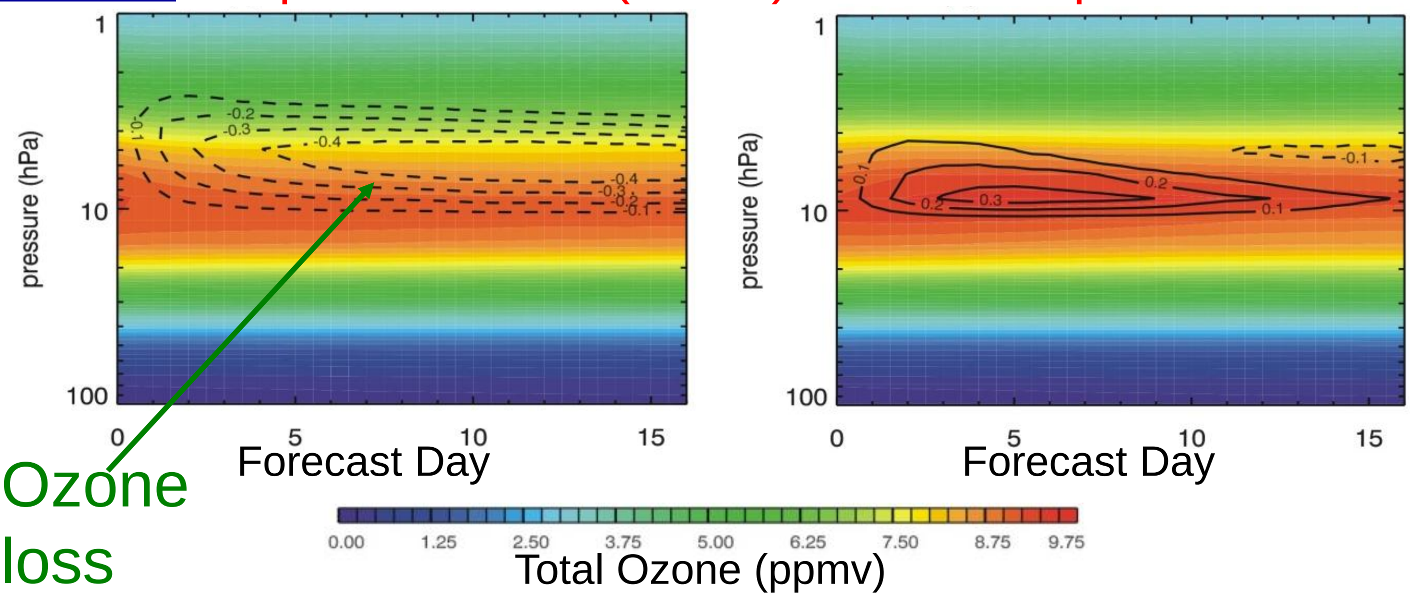
High correlations in Northern Hemisphere midlatitudes where dynamics are an important contributor to ozone variations. Correlations are consistent with measurements taken throughout the record.

[(Brönnimann and Compo 2012)]

Forecasts of Equatorial Stratospheric O_3 mixing ratios using US Navy NOGAPS-ALPHA model with and without CHEM2D-OPP temperature term (June)

$$\frac{\partial \chi}{\partial t}(P-L) = (P-L)_0 + \left.\frac{\partial (P-L)}{\partial \chi_{O3}}\right|_0 \left(\chi_{O3} - \bar{\chi}_{O3}\right) + \left.\frac{\partial (P-L)}{\partial T}\right|_0 \left(T - \bar{T}\right)$$

Without temperature term (~GFS) With temperature term



Ozone loss

Shading: Total O_3

Line Contours show O_3 tendency *from initial condition* (dashed= Loss)

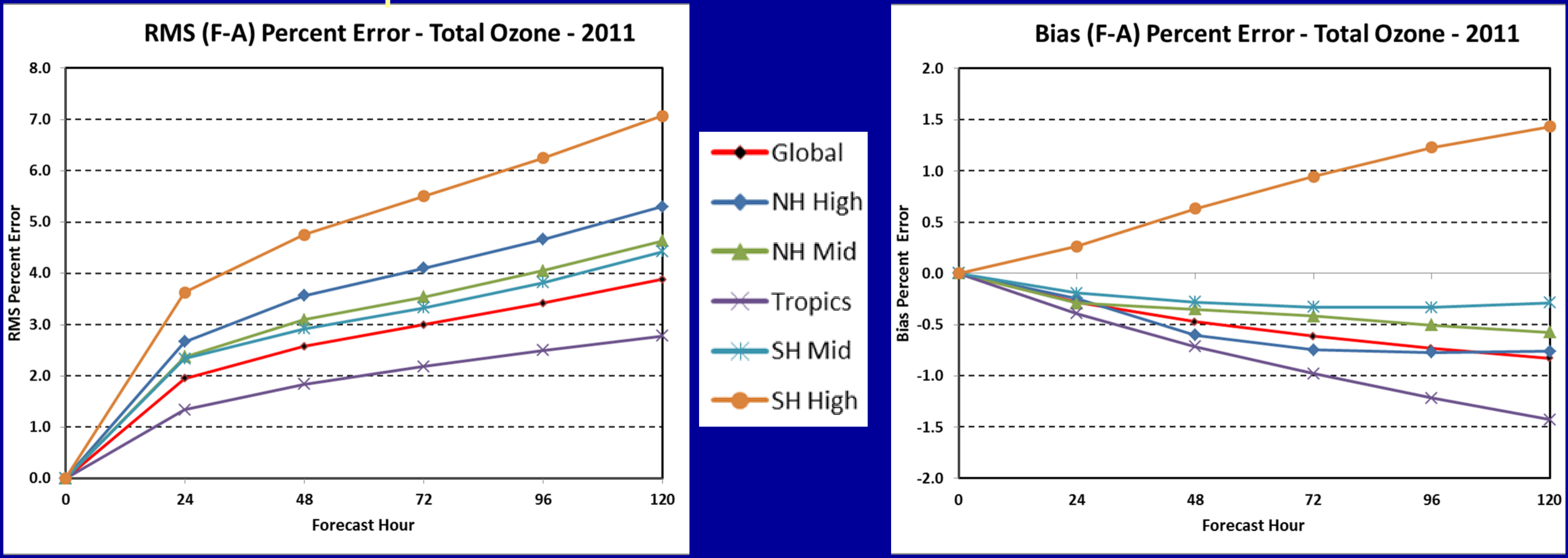
Adding temperature term should significantly reduce unrealistic loss in GFS-type implementation

χ_{O3} prognostic Ozone mixing ratio
T Temperature
c_{O3} column ozone

McCormack et al. 2013

GFS ozone forecast skill for 2011

Root Mean Square Error / Bias



GFS ozone forecast skill degrades significantly after 5 days due, in part, to unrealistic losses over most of the globe resulting in a global negative bias.

Why the loss of ozone? May be related to terms not used.

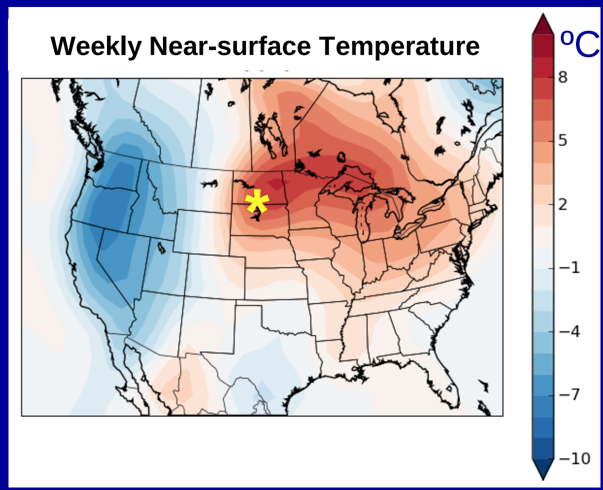
Long et al. 2013

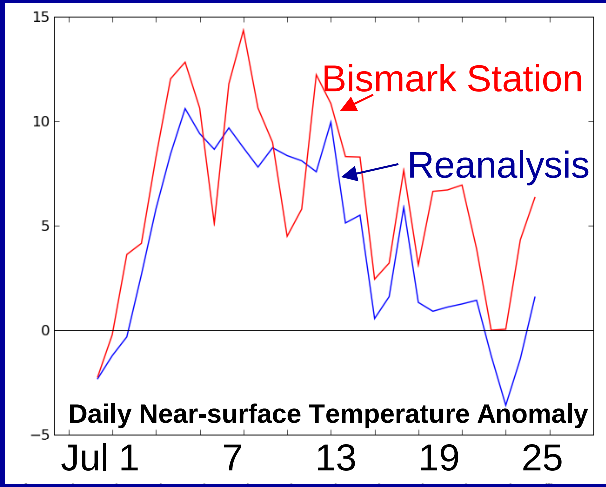
The 20th Century Reanalysis Project (1871-2011)

Summary: An international project led by NOAA and CIRES to produce *4-dimensional* reanalysis datasets for climate applications extending back to the 19th century using an Ensemble Kalman Filter and *only surface pressure observations.*
Research will lead to improved historical reanalysis back to 1850, part of suite of NOAA Climate Reanalyses.

Weekly-averaged anomaly during July 1936 United States Heat Wave (997 dead during 10-day span)

Daily variations compare well with in-situ data.





The reanalyses provide:
-First-ever estimates of near-surface to tropopause 6-hourly fields extending back to the beginning of the 20th century;
-Estimates of uncertainties in the basic reanalyses and derived quantities (e.g., storm tracks).

Examples of uses:
•Validating climate models.
•Determining storminess and storm track variations over the last 150 years.
•Understanding historical climate variations (e.g., Pacific Walker Circulation).
•Estimating risks of extreme events

Compo et al. 2011

Improving the Prognostic Ozone Parameterization in the NCEP GFS and CFS for Climate Reanalysis and Operational Forecasts

PI:	Gilbert P. Compo[1,2]
Co-PIs:	Jeffrey S. Whitaker[2]
	Prashant D. Sardeshmukh[1,2]
	Craig Long[3]
	Shrinivas Moorthi[4]
	Sarah Lu[4]
	John P. McCormack[5]
Collaborator:	Stefan Brönniman[6]

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[2]NOAA Earth System Research Laboratory/Physical Sciences Division

[3]NOAA, National Centers for Environmental Prediction, Climate Prediction Center

[4]NOAA, National Centers for Environmental Prediction, Environmental Modeling Center

[5]Naval Research Laboratory

[6]University of Bern

Naval Research Laboratory
CHEM2D Ozone Photochemistry Parameterization
(CHEM2D-OPP, *McCormack et al. (2006)*)

CHEM2D-OPP is based on gas-phase chemistry circa 2000.
Same approach as used in ECMWF IFS (*Cariolle and Deque 1986*).
Includes ozone depletion from CFCs.

Net ozone photochemical tendency
functional form of Production *P* minus Loss *L*

$$\frac{d\chi_{O_3}}{dt} = (P-L)\left[\chi_{O_3}, T, c_{O_3}\right]$$

Approximate as Taylor series linearized about reference state (denoted by overbar).

$$\frac{\partial \chi}{\partial t}(P-L) = (P-L)_0 + \left.\frac{\partial (P-L)}{\partial \chi_{O3}}\right|_0 \left(\chi_{O3} - \bar{\chi}_{O3}\right) + \left.\frac{\partial (P-L)}{\partial T}\right|_0 \left(T - \bar{T}\right) + \left.\frac{\partial (P-L)}{\partial c_{O3}}\right|_0 \left(c_{O3} - \bar{c}_{O3}\right)$$

χ_{O3} prognostic Ozone mixing ratio
T Temperature
c_{O3} column ozone

Partial use of CHEM2D-OPP in the current NCEP Global Forecast System (GFS) atmosphere/land model

$$\frac{\partial \chi}{\partial t}(P-L) = (P-L)_0 + \left.\frac{\partial (P-L)}{\partial \chi_{O3}}\right|_0 \left(\chi_{O3} - \bar{\chi}_{O3}\right)$$

Reference tendency $(P\text{-}L)_0$ and all partial derivatives are computed from odd oxygen ($Ox \equiv O_3 + O$) reaction rates in the CHEM2D photochemical transport model.

CHEM2D is a global model extending from the surface to ~120 km that solves 280 chemical reactions for 100 different species within a transformed Eulerian mean framework with fully interactive radiative heating and dynamics.

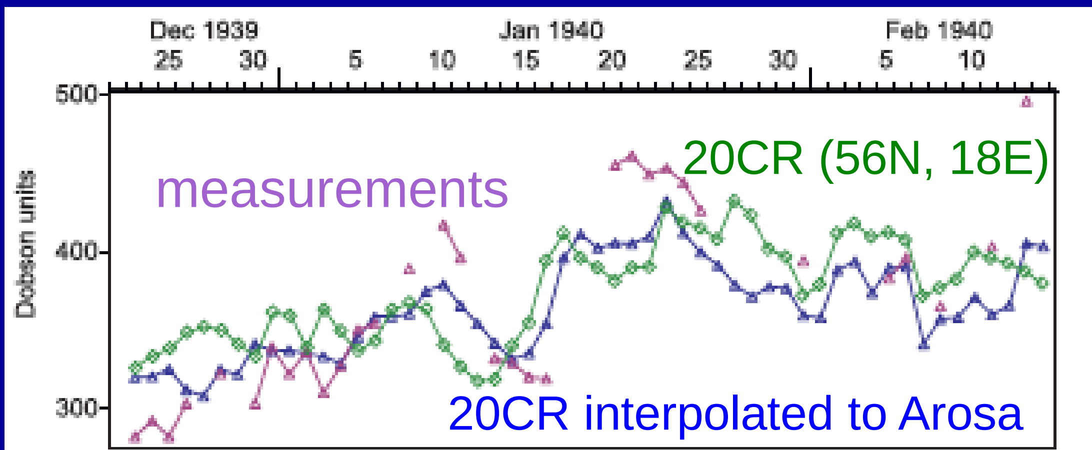
The partial CHEM2D-OPP is used in the 20th Century Reanalysis (20CR) and operational NCEP forecast system, and atmosphere of Climate Forecast System (CFS) Reanalysis (CFSR) and operational CFSv2.

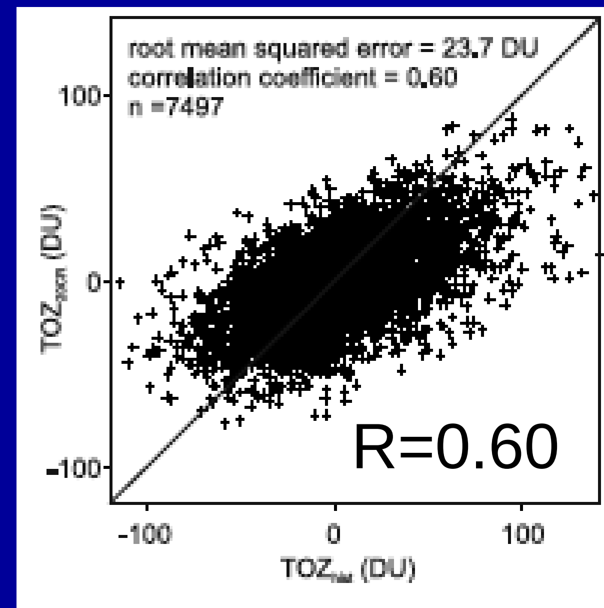
χ_{O3}	prognostic Ozone mixing ratio
T	Temperature
c_{O3}	column ozone

Daily column ozone measurements and 20CR daily ozone at Arosa, Switzerland (46.8N, 9.7E)

Anomaly comparison spanning 1924 to 1963

Dec 1939 Feb 1940





20CR ozone field has large scale fluctuations that reflect ozone highs associated with, e.g., cold air outbreaks. Overall, find high correlations in Northern Hemisphere midlatitudes where dynamics are an important contributor to ozone variations. [(Brönnimann and Compo 2012)].

Issue: Reference state ozone, temperature, and CHEM2D-OPP parameterization coefficients include the chemistry arising from CFCs *throughout the 1871-2011* 20CR record.

Project: new CHEM2D-OPP coefficients and an appropriate ozone climatology will be generated for the period before widespread CFC usage.
Test effects on 20CR fields by comparing to historical ozone observations and to upper-air temperature observations.

Also include additional terms.

Members

David Behringer	NOAA NCEP CPC	Prashant Sardeshmukh	U of Colorado/CIRES & NOAA/ESRL PSD
Jiarui Dong	NOAA NCEP EMC	Fabrizio Sassi	Naval Research Laboratory/SSD
Xiquan Dong	University of North Dakota	Hendrik Tolman	NOAA NCEP EMC
Wesley Ebisuzaki	NOAA NCEP CPC	Russell Vose	NOAA NCDC
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Sarah Lu	NOAA NCEP EMC	Baike Xi	University of North Dakota
John McCormack	Naval Research Laboratory/SSD	Youlong Xia	NOAA NCEP EMC
Jesse Meng	NOAA NCEP EMC	Yan Xue	NOAA NCEP CPC
Kingtse Mo	NOAA NCEP CPC	Rongqian Yang	NOAA NCEP EMC
Shrinivas Moorthi	NOAA Environmental Modeling Center (EMC)	Lisan Yu	Woods Hole Oceanographic Institution
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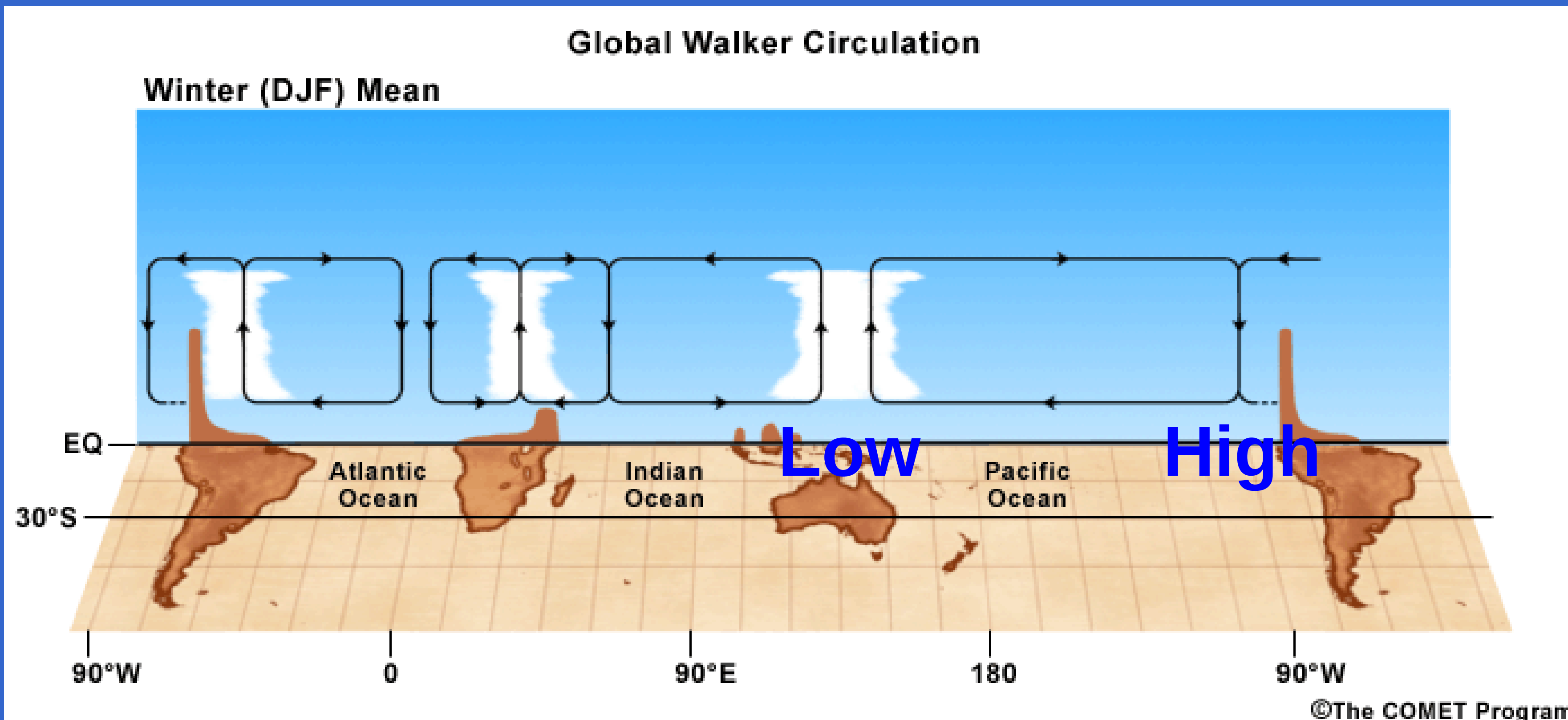
Affiliate	Affiliation
Mike Bosilovich	NASA Goddard
Dick Dee	European Centre for Medium-Range Weather Forecasts


Global Walker Circulation
Winter (DJF) Mean
EQ
30°S
Atlantic Ocean
Indian Ocean
Pacific Ocean
Low
High
90°W
0
90°E
180
90°W
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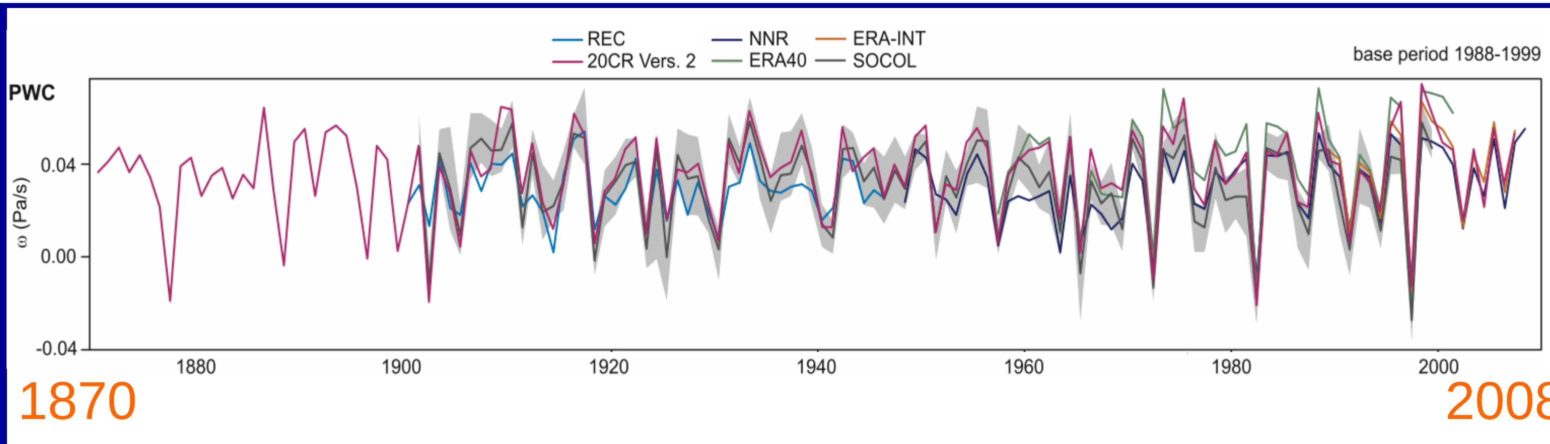
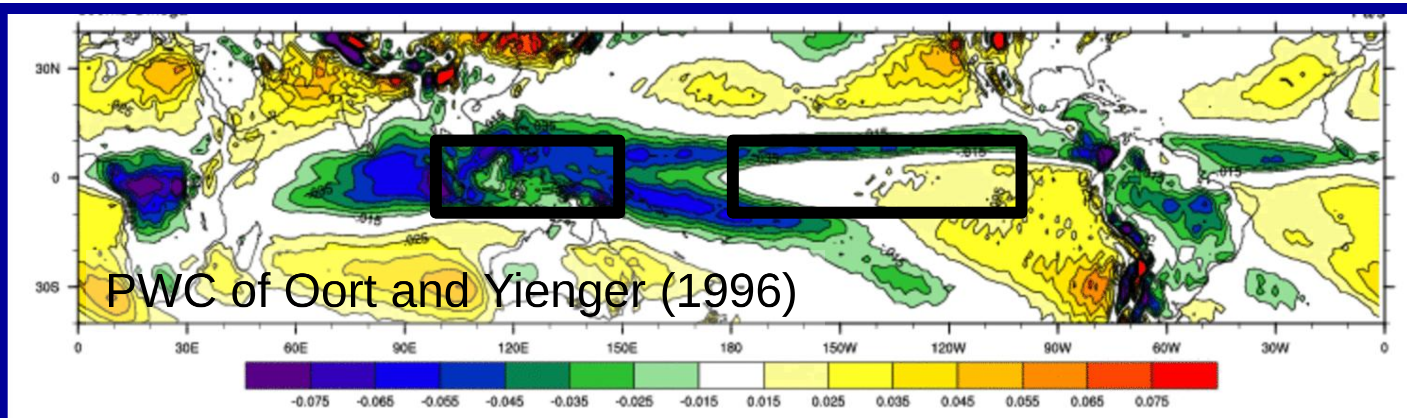
Pacific Walker Circulation from Statistical Reconstructions, AGCM integrations, and 20th Century (20CR), ERA-40, NCEP-NCAR, ERA-Interim Reanalyses.

500 hPa vertical velocity, SONDJ



Climo (ERA-Int)



Agreement in overturning PWC:

correlations between ERA-40 and 20CR > 0.95.

No significant trend in PWC since 1871 using pressure-based 20CR.

Compo et al. 2011